# Advanced Surface Flux Parameterization

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## LONG-TERM GOAL

The long-term goal is to understand the physical processes that critically regulate the coupling between the ocean and atmosphere boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.

## OBJECTIVES

The objective of the research is to improve the surface flux parameterization in Coupled Ocean/ Atmosphere Mesoscale Prediction System (COAMPS) over the ocean with special emphasis on low-wind regimes in collaboration with Coupled Boundary Layer/Air Sea Transfer (CBLAST) community.

## APPROACH

Our first approach is to use COAMPS as a tool in testing and evaluation of existing and newly developed surface flux parameterizations in the context of a mesoscale model. The focus is on the geographical area of the northeast coast of the U. S. establishing a COAMPS grid consistent with the CBLAST observational field program for low-wind (and possibly high wind) events. Measurements from the CBLAST field program will be used to evaluate the current state of parameterizations in COAMPS, including the Louis (Louis, 1979) and COARE surface flux parameterizations (Fairall, et al., 1996). Collaboration with the Rutgers University Coastal Ocean Observation Lab (COOL) will enable COAMPS forecast stresses and fluxes to be evaluated using COOL ocean models during the Long term Ecosystem Observatory (LEO-15) science program operating along the northeast coast. We have used observations from past field experiments, such as TOGA COARE and Japan/East Sea Experiment (JES) to enable systematic evaluation of surface flux parameterizations in a variety of boundary layer and large-scale conditions. In addition, we used COAMPS to examine and improve the representation of surface fluxes when the horizontal grid resolution reduces to sub-kilometer scales.

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14. ABSTRACT
**The long-term goal is to understand the physical processes that critically regulate the coupling between the ocean and atmosphere boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.**

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The second approach is to use turbulence data from the field experiments to test and improve the COAMPS surface and boundary layer parameterizations as single column models without the surface-boundary layer-mesoscale interaction. The effort is focused on the detailed physical process parameterizations (such as the gustiness, boundary layer turbulent mixing and roughness length *etc*.).

## WORK COMPLETED

1. A month long (July, 2000) high-resolution (45, 15 and 5 km nested grid spacing) reanalysis simulation over LEO-15 experiment area using COAMPS has been performed and analyzed to provide atmospheric forcing to the COOL ocean models.

2. To assist operational planning of the July-August 2001 pilot CBLAST-Low experiment, we conducted a two-week high-resolution (13.5, 4.5 and 1.5 km for nested horizontal grid resolutions) reanalysis (19 July – 6 Aug., 1999) over the target area and performed a detailed analysis of the interactions between mesoscale circulations and near-surface turbulence structure. Based on this analysis, a case and relevant COAMPS products were provided to Peter Sullivan of NCAR to examine fluxes using a large-eddy simulation model

3. We performed twice daily real-time forecasts for both LEO-15 and CBLAST-Low experiments from 1 July – 10 August, 2001 using high resolution COAMPS (54, 18 and 6 km horizontal resolution) making use of the COARE surface flux parameterization over ocean. During this period, a 48 hour COAMPS forecast was produced every 12 hours except for 00Z Wednesday and 00Z Sunday when a 72 hour forecast was produced to provide necessary atmospheric forcing for LEO-15 ocean model predictions. Currently, we are evaluating the forecasts with the various observations.

4. We analyzed current COAMPS surface flux parameterizations with TOGA COARE surface turbulence flux data for low-wind speed regime using a one-dimensional model approach. Based on this analysis, we have proposed an improved COAMPS operational surface flux parameterization.

5. To understand the scale-dependence of surface flux and boundary layer parameterizations in high-resolution mesoscale models, we performed intensive analyses on COAMPS simulations of a post-frontal case observed during JES. In particular, we made spectral analyses to the model resolved field to understand the contribution of ‘resolved’ large turbulence eddies to the ensemble turbulent fluxes at very high horizontal grid resolution (1 km and 0.5 km for the inner-most grid, respectively). These results are compared to direct measurements in the model domain.

6. We have made preliminary analysis of the NCAR Electra measurements during TOGA COARE in search of appropriate cases for COAMPS surface flux evaluation in the future. These low-wind cases, mostly with unstable surface stratification, will be valuable addition to the CBLAST low-wind measurements where stable stratification may dominant. Future COAMPS simulations for the TOGA COARE cases are planned.

## RESULTS

*COAMPS CBLAST Reanalysis*: We found that, apart from synoptic weather pattern and sea surface temperature, the diurnal varying land-sea circulation is a critical controlling factor of the local surface turbulence structure and marine boundary layer characteristics in the CBLAST-Low area. During the daytime, the relatively warmer on-shore flow from south produces a stable marine boundary layer in the coast area of Martha Vineyard Island, while the cool off-shore flow during the night creates an unstable boundary layer over the water. A relatively stable marine boundary layer was expected during the experiment because of two factors: the dominant wind direction in the area is onshore associated with southwesterly flow, and also the SST is still not maximized yet.

*COAMPS Real-Time Forecasts* : The real-time forecasts using COAMPS contributed significantly to the overall success of the ocean model forecasts in LEO-15 field experiment this year. An example of a forecast from COAMPS along with tower observations (courtesy of Rutgers University COOL lab) are shown in Fig. 1.

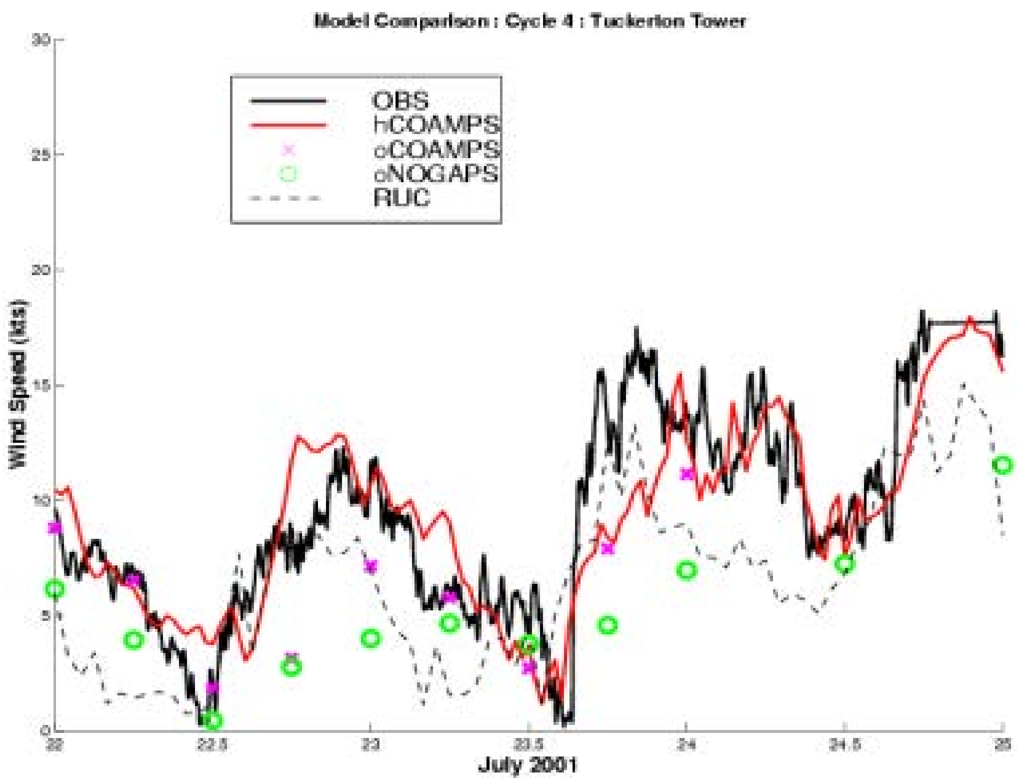


***Figure 1. Real-time forecast for CBLAST-Low and LEO15 for July – August, 2001. [Wind speed from the Tuckerton tower ( ---- ), COAMPS CBLAST-low domain (----), operational COAMPS area (Δx=27 km)(x), NOGAPS (o) and NCEP RUC (- - - -).]***

*Evaluation of the Surface Flux Parameterization with COARE Flux Data*: Based on the analysis, we found that current COAMPS flux parameterization has several deficiencies.

(a) The gustiness factor in the wind speed calculation, designed to account for the large-eddy contribution in convection, is significantly larger than that derived from the observations as shown in Fig. 2.

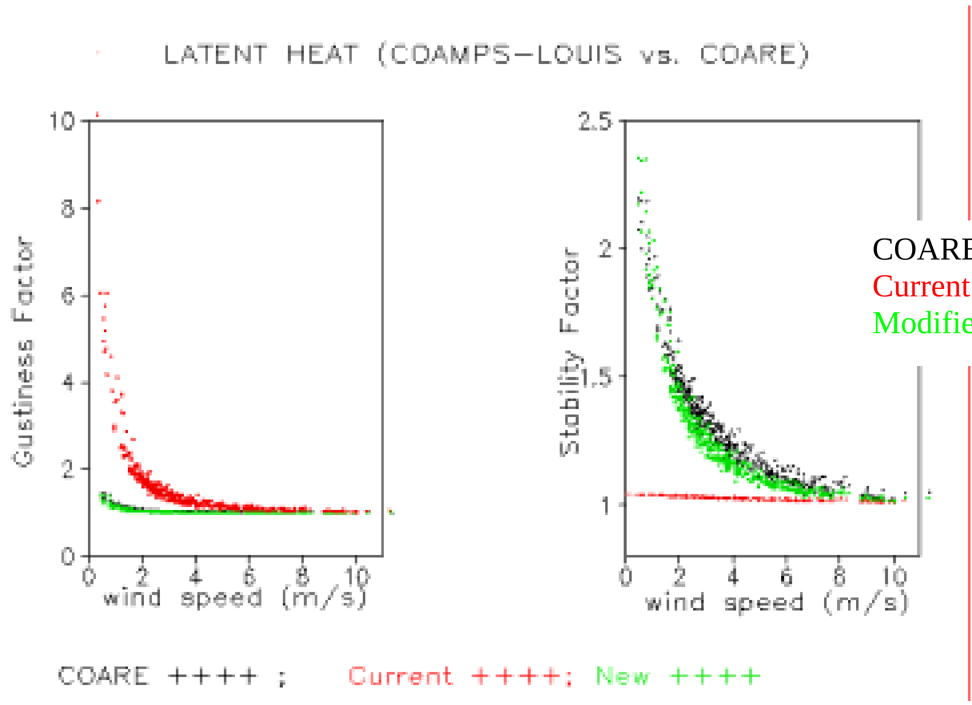


***Figure 2. Current and modified COAMPS latent heat flux parameterization vs. COARE Scheme [Left: Gustiness Factor; Right: Stability Function.]***

The COARE scheme's gustiness is consistent with the well-documented observations that the convective velocity is on the order of ~ 1 $ms^{-1}$. We have modified the gustiness coefficient and the Louis stability functions based on the observations and Monin-Obukhov universal function as shown in Fig. 2.

(b) Currently, the surface wind stress in COAMPS is formulated in terms of average wind speed instead of magnitude of grid scale wind vectors. Therefore, the stress values actually represent those produced by ***total*** wind speed (i.e., mean wind plus large eddy turbulent eddies). Specifically, a correct formulation should result in zero stress when grid-scale mean wind vanishes in a mesoscale model. The COAMPS formulation does not meet this necessary condition and needs to be modified.

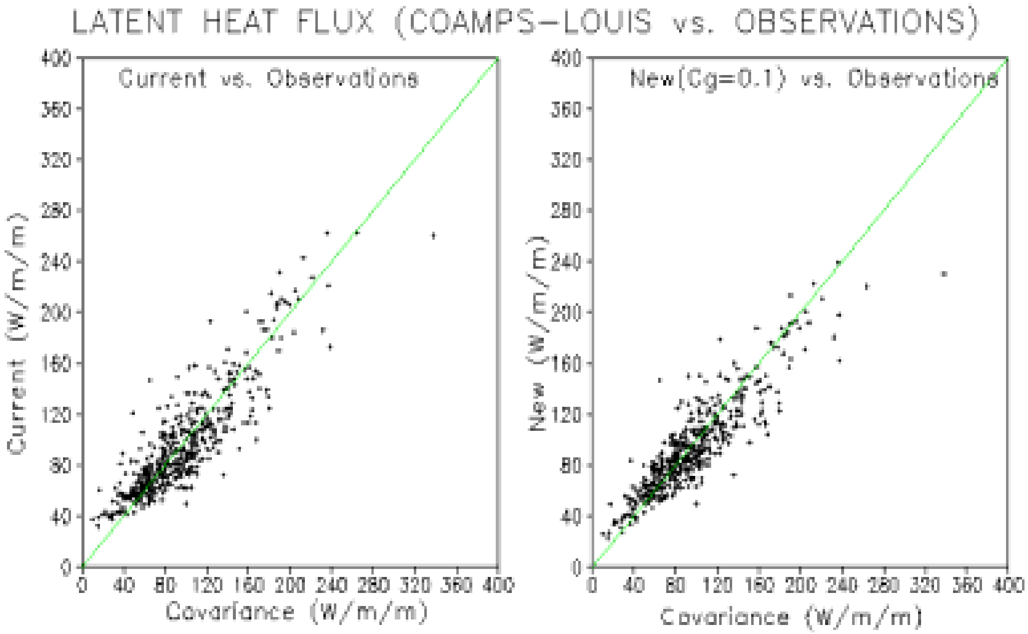


***Figure 3. Current and new latent heat fluxes vs. COARE observations (denoted by covariance) [Left: current vs. observation; Right: modified scheme vs. observations]***

(c) In the current COAMPS, roughness lengths for heat and moisture are taken to be 10% of momentum roughness length. It is well known that the ratio between the dynamic and heat roughness lengths over a rough surface is a function of surface turbulence characteristics. To account for this condition, we introduced the simple roughness length formulation developed in COARE2_6 (Bradley et al., 2000) to the COAMPS scheme. The performance of the current COAMPS and modified latent heat flux parameterization against the covariance flux derived from the Moana R/V observations during TOGA COARE are shown in Fig. 3. Clearly, the modifications have reduced the scatter and the intercept value of the COAMPS parameterization.

*Scale dependence of surface fluxes in sub-kilometer resolution mesoscale models:* From this initial effort, we found: 1) The perturbations close to the smallest resolvable scale of the model are very sensitive to grid resolution. Compared to observations, these scales are not adequately represented in COAMPS, even though they are explicitly resolved. 2) The model parameterized turbulent fluxes, derived from ensemble turbulence statistics, are not sensitive to the grid resolution even though subgrid fluxes are observed to be strong functions of the cutoff wavelength. And 3) There are large discrepancies between the parameterized and the observed SGS turbulence fluxes. All these results point to large uncertainties in the exchange coefficients in the surface flux parameterizations in high-resolution mesoscale models. The sensitivity of variances in the resolvable scales to horizontal grid resolution is shown in Fig. 4.

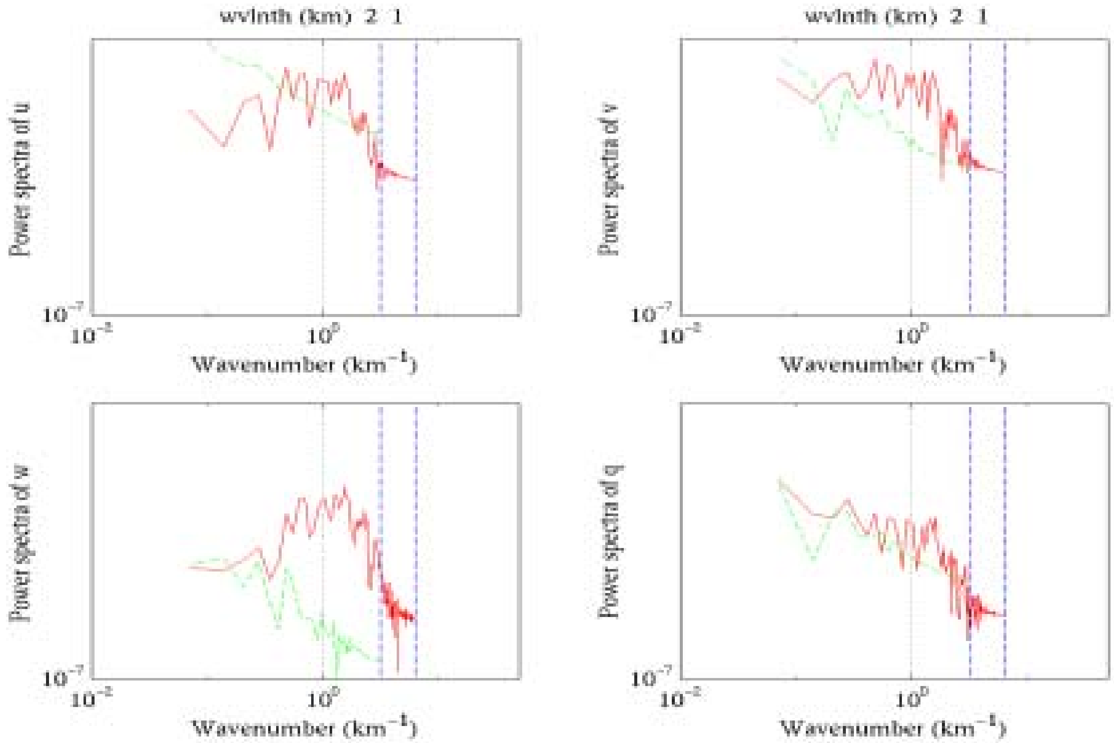


***Figure 4. Comparisons of power spectra from two high-resolution COAMPS simulations. [Solid: 0.5 km horizontal resolution; Dash: 1 km resolution. The two vertical dash lines denote the minimum resolvable scale from each model run.]***

## IMPACT/APPLICATIONS

We have made a number of modifications in the methodology for representing subgrid-scale surface fluxes on the mesoscale. We anticipate that these modifications to surface flux parameterization ultimately will improve the COAMPS forecast skill. We have also collected a large number of observational cases for future evaluation of COAMPS with newly developed surface flux parameterizations.

## TRANSITIONS

The improved surface flux parameterization is currently being tested in the latest version of COAMPS and will be will transitioned to 6.4 programs (PE 0602435N and PE 0603207N) for applications within COAMPS and for subsequent transition to Fleet Numerical Meteorology and Oceanography Center (FNMOC) and regional Naval Meteorology and Oceanography Centers for operational use.

## RELATED PROJECTS

Related 6.2 projects within PE 0602435N are BE-35-2-18, for the *Mesoscale Modeling of the Atmosphere and Aerosols*, BE-35-2-19, and for the *Exploratory Data Assimilation Methods*. Related project at NPS is N0001401WR20242 for *Evaluating Surface Flux and Boundary Layer Parameterizations in Mesoscale Models Using Measurements from the Japan/East Sea Experiment.*

## SUMMARY

Modifications have been made to improve the current representation of surface fluxes in the Navy's COAMPS mesoscale model through the use of high-resolution, retrospective reanalysis and real-time forecasts. Accurate representation of fluxes at the air-sea interface is a necessary step in the process of building a fully coupled air-ocean prediction system.

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